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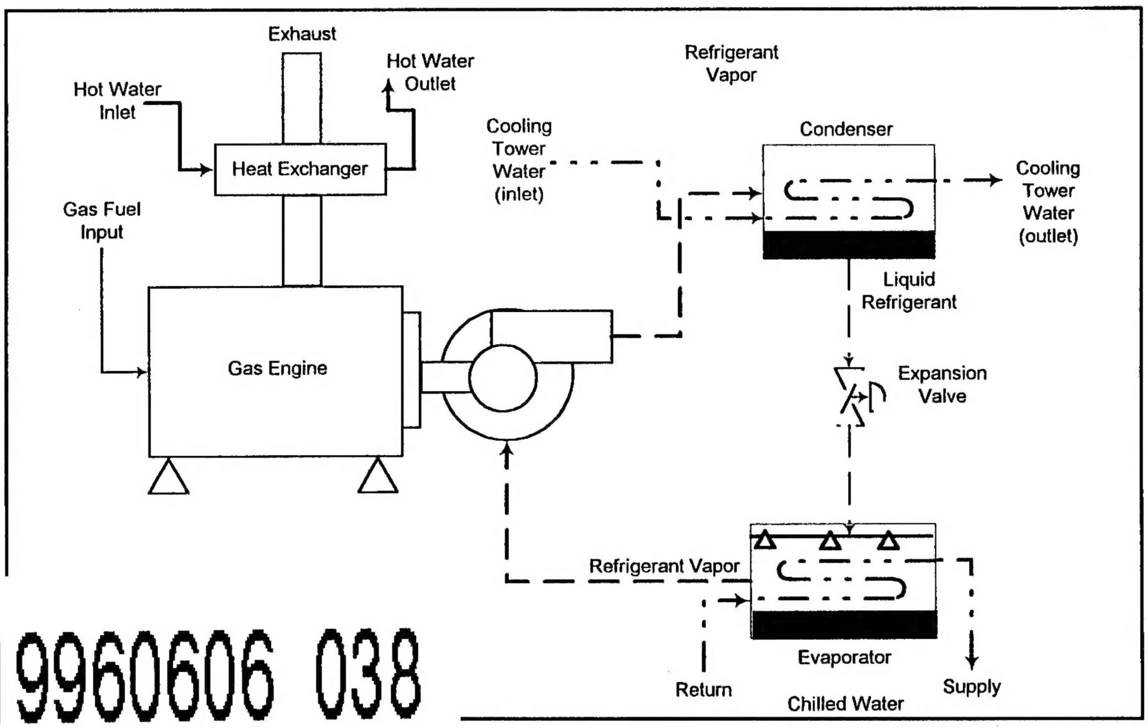
Gas-Fueled Cooling Technologies at DOD Fixed Facilities

by
Timothy W. Pedersen, Michael K. Brewer, Daryl Matsui, Richard E. Rundus, Thomas E. Durbin, Christopher L. Dilks, Michael A. Caponegro, and Ralph E. Moshage



Approximately one-third of all energy consumption and two-thirds of total energy expenditures at Department of Defense (DOD) fixed facilities are electricity related. Summer air-conditioning loads account for 30 to 60 percent of the total energy expenditures. Moreover, peak cooling requirements at DOD facilities generally occur when utility rates are highest. This portion can exceed 50 percent of an installation's total bill.

At DOD fixed facilities, energy costs can be reduced by conserving electrical energy or by replacing electrical consuming devices with alternate fuel-driven mechanisms, such as those that use natural gas, which currently accounts for only 38 percent of the fuel consumed and 20 percent of total energy expenditures. Absorption chillers, engine-driven chillers, and desiccant-based air-conditioning units are possible alternatives to electric cooling equipment. Using these state-of-the-art gas cooling technologies to replace existing electric-driven cooling devices may reduce the installation's electric demand, provide domestic hot water, and lessen environmental impacts normally attributed to electric-driven chillers. This study evaluated the effectiveness of gas cooling technologies at selected DOD installations.

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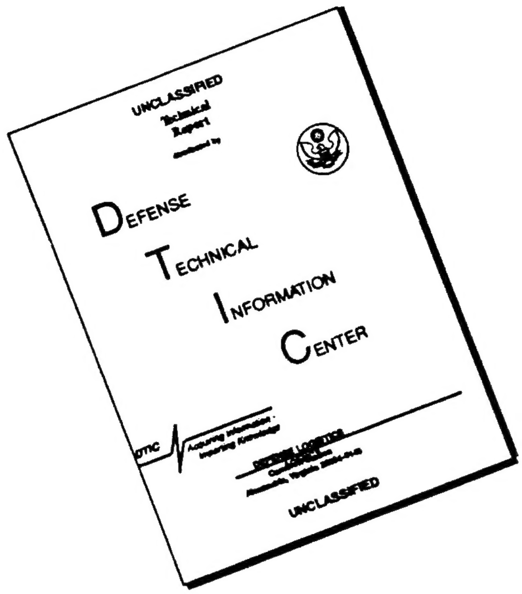

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At DOD fixed facilities, energy costs can be reduced by conserving electrical energy or by replacing electrical consuming devices with alternate fuel-driven mechanisms, such as those that use natural gas, which currently accounts for only 38 percent of the fuel consumed and 20 percent of total energy expenditures. Absorption chillers, engine-driven chillers, and desiccant-based air-conditioning units are possible alternatives to electric cooling equipment. Using these state-of-the-art gas cooling technologies to replace existing electric-driven cooling devices may reduce the installation's electric demand, provide domestic hot water, and lessen environmental impacts normally attributed to electric-driven chillers. This study evaluated the effectiveness of gas cooling technologies at selected DOD installations.

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Foreword

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Support Office under Funding Acquisition Document (FAD) No. 95-080009; Work Unit 95-080009, "Natural Gas Air-Conditioning Demonstrations." The technical monitor was Michael Hathaway, SERDP, Program Manager for Energy Conservation/Renewable Resources Technology Thrust Area.

The work was performed by the Utilities Division (UL-U) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Michael Brewer. Daryl Matsui is associated with the Naval Facilities Engineering Service Center (NFESC). Martin J. Savoie is Chief, CECER-UL-U; John T. Bandy is Operations Chief, CECER-UL; and Gary W. Schanche is Chief, CECER-UL. The USACERL technical editor was William J. Wolfe, Technical Resources Center.

COL James T. Scott is Commander and Acting Director, and Dr. Michael J. O'Connor is Technical Director of USACERL.

Contents

1 Introduction

Background

Approximately one-third of all energy consumption and two-thirds of total energy expenditures at Department of Defense (DOD) fixed facilities are electricity related. Summer air-conditioning loads account for 30 to 60 percent of the total energy expenditures. Another major energy resource available to DOD fixed facilities is natural gas, which accounts for only 38 percent of the fuel consumed and 20 percent of total energy expenditures.*

The apparent high cost of electricity is a result of peak cooling loads that can occur over short periods of time and can cause high fluctuations in the utility load profile. Utility companies must therefore operate expensive and inefficient peaking plants to meet this demand. This extra cost is passed to the consumer in the form of Time-of-Day and seasonal variation rates, seasonal variations in demand charges, and/or a ratchet clause.

Peak cooling requirements at DOD facilities generally occur when utility rates are highest. This portion can exceed 50 percent of an installation's total bill. At DOD fixed facilities, these energy costs can be reduced by conserving electrical energy or by replacing electrical consuming devices with alternate fuel-driven mechanisms. Absorption chillers, engine-driven chillers, and desiccant-based air-conditioning units are all being evaluated as possible alternatives to electric cooling equipment. Benefits from using these state-of-the-art gas cooling technologies to replace existing electric-driven cooling devices include reducing the installation's electric demand, providing domestic hot water, and lessening environmental impacts normally attributed to electric-driven chillers. This study was undertaken to evaluate the effectiveness of gas cooling technologies at DOD installations.

* Cler, Gerald L., *Evaluating Gas-Fueled Cooling Technologies for Application at Army Installations*, Technical Report (TR) 95/14 (U.S. Army Construction Engineering Research Laboratory [USACERL], November 1995).

Objective

The objective of this study was to evaluate the effectiveness of gas cooling technologies at DOD installations through a series of field demonstrations.

Approach

Candidates for gas cooling technologies include DOD facilities such as hospitals, barracks, and other facilities that require large cooling loads and hot water capabilities. SERDP funding was leveraged against moneys from the fiscal year 1993 (FY93) Defense Appropriations Act and the follow-on appropriations from the FY94 and FY95 budgets. These funds were designated for the procurement of "natural gas chillers for the air-conditioning of DOD facilities." Strategic Environmental Research and Development Program (SERDP) funds were to be used to:

1. *Investigate potential implementation sites.* Potential sites were screened for candidacy by taking into consideration the electric and natural gas rate structures, cooling and hot water load profiles, and site-specific operating conditions. This process reduced the list of possible sites to a few candidates. U.S. Army Construction Engineering Research Laboratories (USACERL) researchers visited these installations to: (a) determine the appropriate gas cooling technology for funding, and (b) gather site-specific information concerning the design and estimated installation costs of the proposed system.

2. *Develop equipment purchase documentation.* Equipment purchase documentation was developed for the sites shown to be good candidates for gas cooling technology. This document included equipment purchase, installation, start-up, acceptance testing, and first year warranty and maintenance information. Energy efficiency and environmental performance requirements, acceptance testing standards, equipment manufacturer qualifications, mechanical contractor qualifications, and a selection criteria for bid evaluation were optional parts of the package.

3 *Supervise the equipment installation and acceptance.* Equipment purchasing, installation, and acceptance testing were completed for approved sites. The standard documentation developed in the previous task were used as the basis for a Invitation for Bid (IFB). This IFB was advertised for each implementation site identified in the second task. On contract award, USACERL and Naval Facilities Engineering Service Center (NFESC) personnel assisted in the design review stage and inspection of installed systems. USACERL and NFESC representa-

tives also helped supervise and evaluate the acceptance testing results for the installed system. If requested, a summary report of each implementation site documenting all aspects of the project was also done as part of this task.

4. *Monitor equipment performance.* Monitoring equipment has been installed at several facilities with the intent to record data for a span of 1 or 2 years. The data recorded to help determine the applicability of particular technologies to facilities throughout the DOD. Preparations were made to monitor additional sites as construction processes. Both technical and economical aspects of system performance were to be monitored.

5. *Document "lessons learned" to assess the applicability of these technologies throughout the DOD.* This task was programmed for FY96 and FY97, and is detailed—as accomplished to date—in this report. Although SERDP funding is not currently available to complete these tasks, this report documents work supported in part by the SERDP Project 643, "Natural Gas Based Air-Conditioning Demonstration."

Environmental and Economic Benefits

Gas cooling technologies can offer DOD installations environmental and economic benefits. The environmental benefit stems from the fact that the technologies use refrigerants with lower ozone-depleting potential. Absorption and desiccant chillers are free of ozone-depleting CFC and HCFC compounds while engine-driven chillers typically use HCFCs or HFCs with low or zero ozone-depleting potential. The economic benefits of gas cooling can vary since gas chiller equipment costs are higher than conventional electric-driven vapor-compression equipment.

To help offset this cost differential, areas with large electric-to-gas cost ratios were the first considered for gas cooling technology. This minimized the payback period for the incremental cost of the project. To reduce peak electric demand and increase summer gas sales, many gas and electric utilities offer rebates for unit installations on a per-ton basis. Sometimes these rebates alone make up the equipment cost differential. Some gas utilities also offer reduced rates to facilities using gas for cooling purposes. Some applications reduce costs in other areas by providing energy to produce domestic hot water and/or boiler makeup water. Use of these applications increases the system's overall cost effectiveness.

2 Types of Chillers

Absorption Chillers

Absorption chiller technology has been in existence for over 100 years. The first patent was issued in 1859, and further technological advances occurred into the 1860s. Absorption cooling systems were fine tuned for commercial use by large manufacturers in the 1850s and 1860s, but their popularity declined in the late 1870s due to the lower cost and increasing abundance and use of electricity. Absorption chillers use a technology similar to the vapor-compression cycle, i.e., absorption chillers rely on a cycle of condensation and evaporation to produce cooling. However, the mechanical compressor of the vapor-compression cycle is replaced by a heat source in the absorption chiller. This heat source is either direct-fired via a burner or indirect-fired via steam, hot water, or waste heat from other processes.

Figure 1 shows a single-effect (single-stage) lithium bromide/water absorption chiller. The principal components that make up the cycle are:

1. *Evaporator.* As the building chilled water circulates through the evaporator, it releases heat to the low-pressure liquid refrigerant. The refrigerant boils and is transferred to the absorber.

2. *Absorber.* The cold, low-pressure refrigerant vapor entering the absorber is absorbed by the lithium bromide (absorbent) to form a liquid solution of lithium bromide/water. This solution is then pumped up to the condenser pressure using a liquid pump. Heat is released to the cooling tower water during the absorption process.

3. *Generator.* The generator is the most energy intensive step of the absorption chiller. The heat input from the burner boils off the refrigerant, which flows to the condenser. The resulting concentrated lithium bromide solution is pumped back to the absorber. Sometimes the lithium bromide solution is passed through a liquid-to-liquid heat exchanger as a preheater for the lithium bromide/water solution before entering the generator.

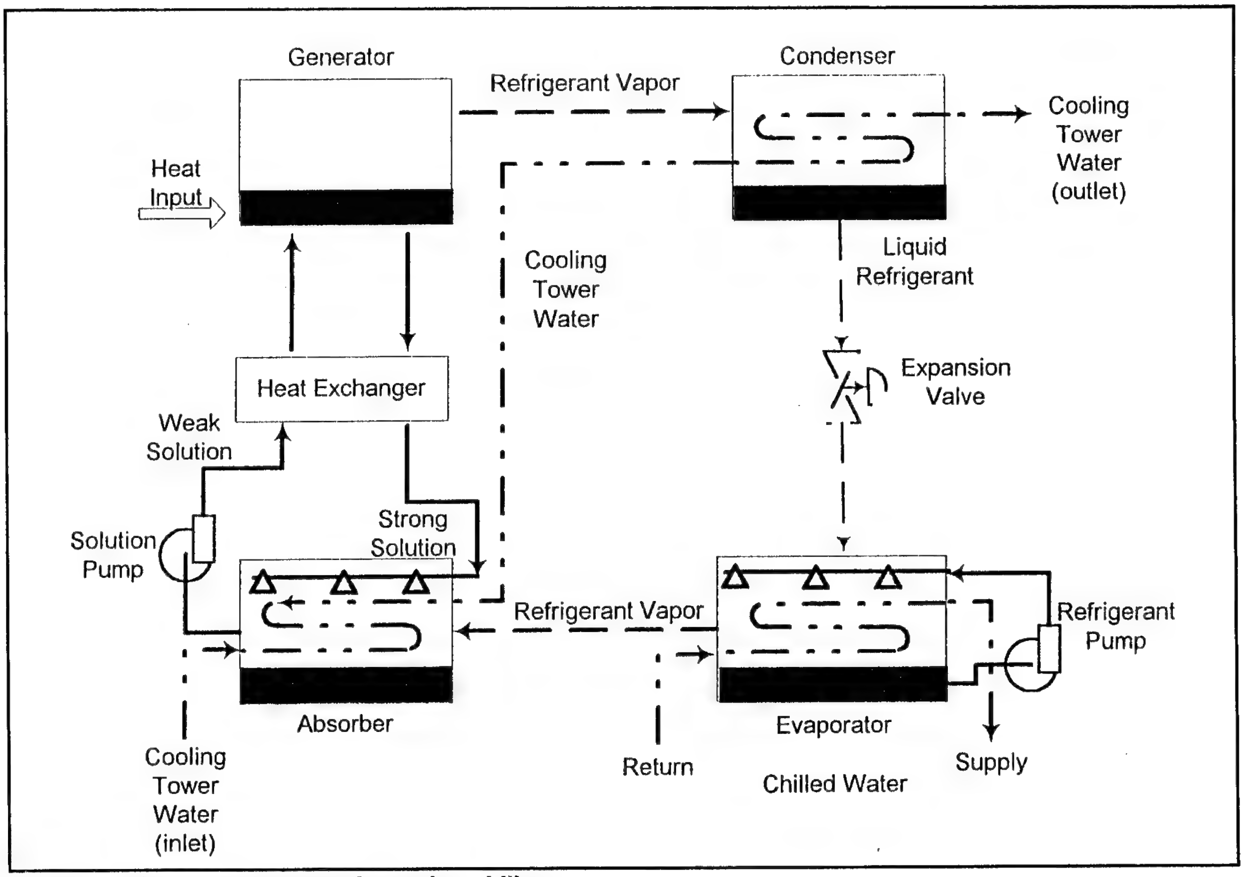

Figure 1. Single-stage water absorption chiller.

4. *Condenser*. The hot liquid refrigerant enters the condenser where it is cooled and condensed to a liquid. Heat is again released to the cooling tower water and the hot liquid refrigerant is expanded into the evaporator.

The thermal Coefficient of Performance (COP) for single-effect absorption chillers (typically indirectly fired) range from 0.6 to 0.75. This calculation necessitates the inclusion of the boiler efficiency since it is the source of the hot water or steam used as heat input into the generator. The supplied heat should be hot water at approximately 210 °F or steam at 18 psig.*

Manufacturers quickly became aware that performance could be improved by adding a second effect or stage to the existing single-effect chiller. These two-stage, or double-effect systems (Figure 2), operate in the same basic manner as single-effect systems with the following additions:

1. *Low Temperature Generator.* The high temperature vapor refrigerant from the high temperature generator is used as the heat source in the low temperature

* °F = (°C × 1.8) + 32; 1 psi = 6.89 kPa.

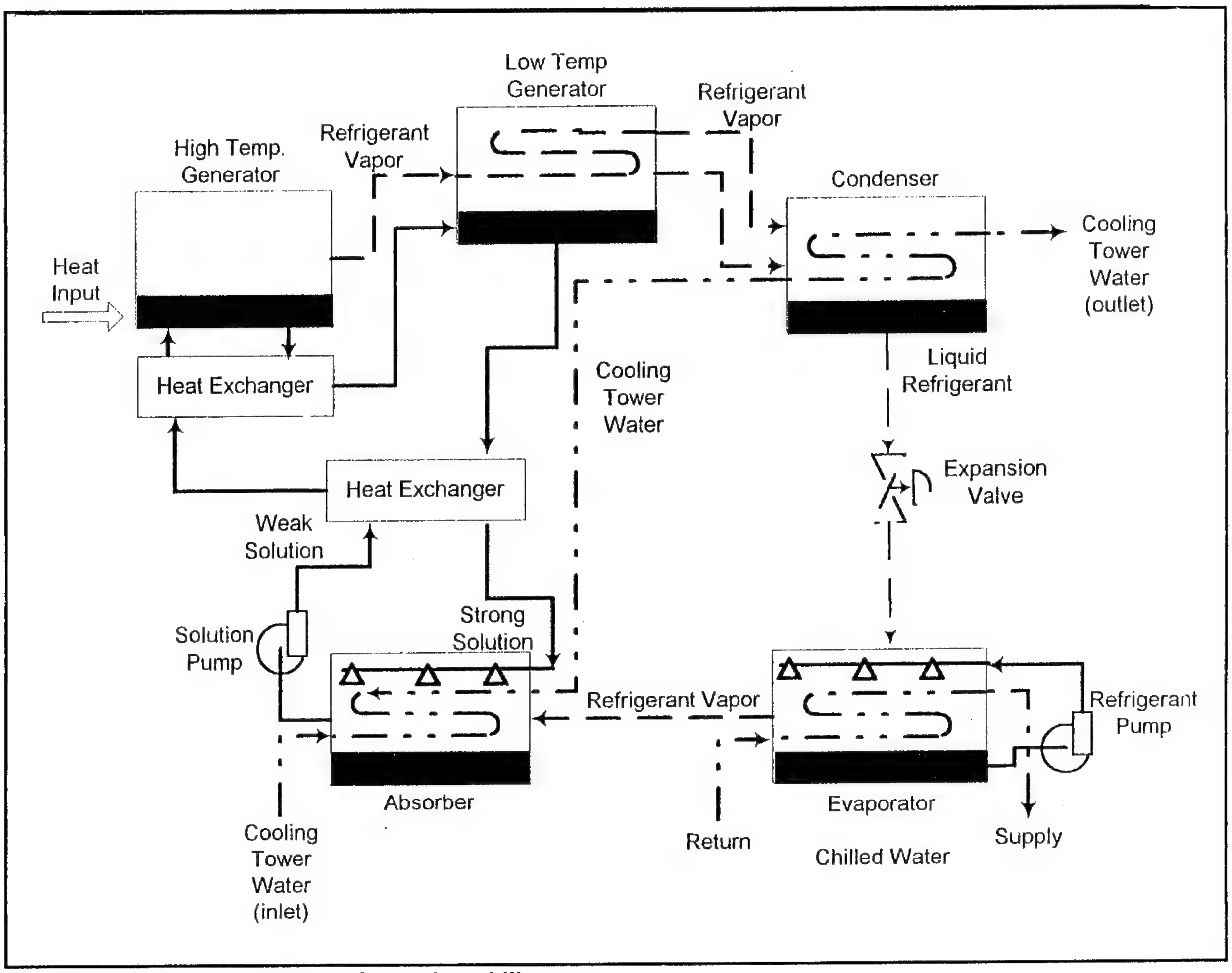

Figure 2. Double-stage water absorption chiller.

generator. This step produces more refrigerant while cooling the refrigerant in preparation for entrance into the condenser.

2. *Second Liquid-to-Liquid Heat Exchanger*. In addition to the first liquid to liquid heat exchanger, a second is added to recover heat from the lithium bromide solution leaving the low temperature generator. The addition of this heat exchanger increases cycle efficiency.

The COP for indirect-fired double-effect absorption chillers range from 1.2 to 1.46. Boiler efficiency is not included in the energy consumption calculations. Direct-fired double-effect absorption chillers have a lower COP with values ranging from 0.90 to 1.10. Boiler efficiency is not considered since the generator is directly-fired and the efficiency is accounted for during the COP calculations. Generator temperatures required for double-effect chillers can approach 300 °F with steam pressures of 120 psig. Consequently, direct-fired units must be fueled by natural gas or oil.

Absorption chillers can reach 10 percent capacity while maintaining relatively good efficiencies. Part loads are achieved by varying the flow of steam or firing rate of the burner, which changes the production of concentrated absorbent. To enhance part-load performance, some units use multiple capacity burners.

Gas Engine-Driven Chillers

Gas engine-driven chillers have been successfully marketed in the United States since the 1960s. Gas shortages in the mid-1970s and an increase in market shares moving toward electric cooling systems have virtually destroyed the market for gas engine-driven chillers. Still, properly maintained engine-driven systems are highly reliable.

An engine-driven chiller is similar to an electric chiller except the motor that would drive a electric chiller is replaced by a gas engine (Figure 3). An open drive configuration is required since the engine must be housed outside the compressor casing. The waste heat from the engine could be used for service water heating or as the steam provider for an absorption chiller unit. The system operates in the same manner as conventional vapor compression cycle except for a few minor changes:

1. *Evaporator.* As the building chilled water circulates throughout the evaporator, it releases heat to the low-pressure liquid refrigerant, causing it to boil.

2. *Compressor.* The engine-driven compressor pulls the refrigerant vapor from the evaporator and compresses it to a higher temperature and pressure.

3. *Condenser.* The high temperature and pressure refrigerant enters the condenser where the cooling water or air cools the refrigerant, causing it to condense to liquid form.

4. *Expansion Valve.* The liquid refrigerant is then passed through an expansion valve into the evaporator. This reduces the pressure and temperature of the refrigerant.

The performance of engine-driven chillers is primarily a function of the gas-engine efficiency and the compressor COP. The efficiency for a gas engine ranges from 0.27 to 0.33; the compressor COP ranges from 4.5 to 6.5. (The lower efficiency value is for a reciprocating type compressor and the higher value is for a screw-type compressor.) A combined COP for the chiller plant will range from 1.22 to 2.15.

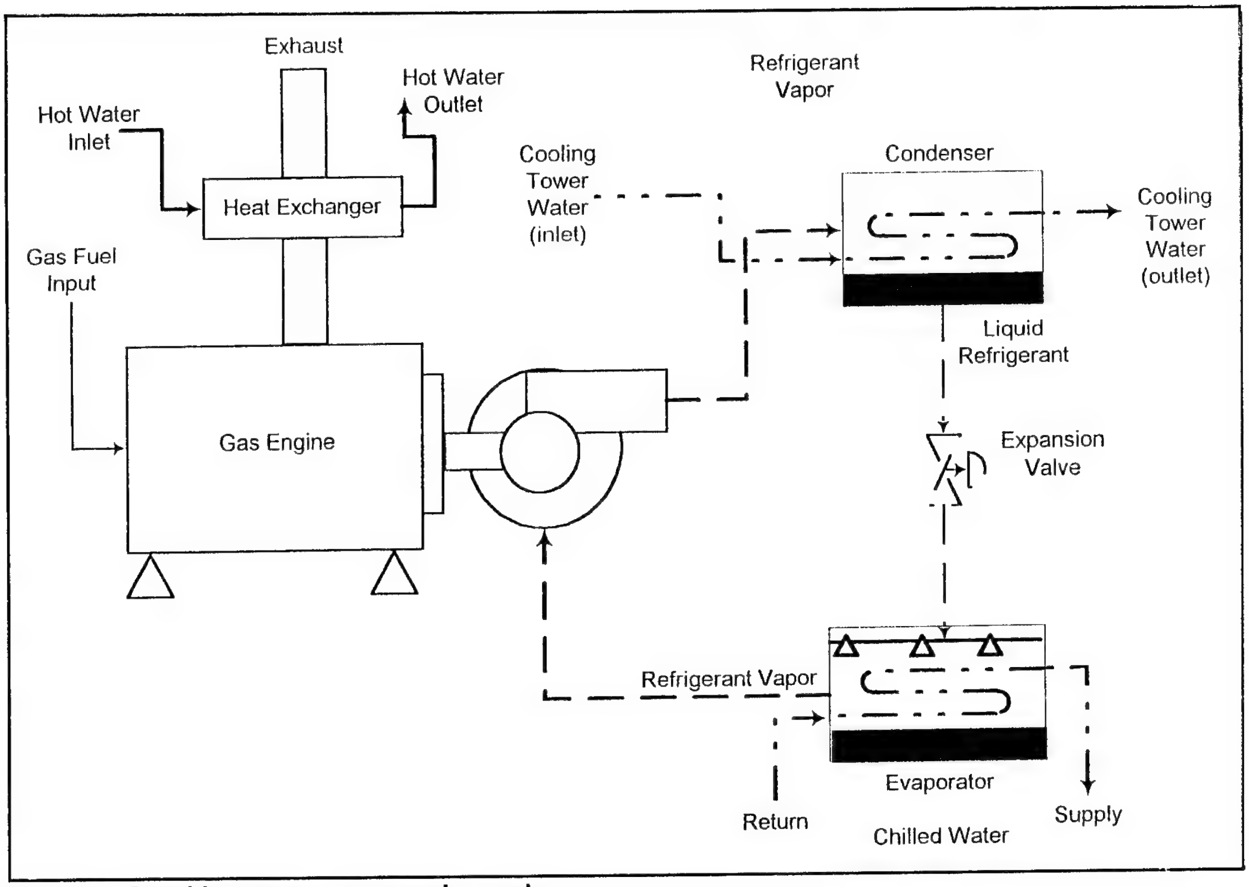

Figure 3. Gas-driven vapor compression cycle.

In general, the COPs for engine-driven chillers are slightly higher than those for absorption chillers. The increase in performance translates into cooling towers that are smaller than those required by absorption chillers yet larger than those required by electric chillers. Note that an engine-driven chiller requires more maintenance than a comparable absorption or electric-driven unit.

The ability to operate an engine-driven chiller at off-loads by modulating the engine speed results in good part-load performance. A screw compressor maintains good part-load performance down to 10 percent because of its ability to operate at variable displacements. A reciprocating compressor offers good off-load performance down to about a 50 percent load. At that point, the engine speed must remain constant and further reduction in load is accomplished by unloading the cylinders. It is in this regime where part-load performance degrades rapidly.

Desiccant Dehumidification System

Desiccant systems use either absorption or adsorption processes to dehumidify the air. Common desiccants are lithium chloride, silica gel, and molecular sieve. As the air passes through the desiccant, latent heat load is converted to a sensible heat load resulting in warm, dry air. This air is then cooled to the desired process air temperature.

By contrast, a conventional vapor-compressor chiller cools the air to be conditioned below its dew point thereby causing the moisture in the air to condense in the evaporator. The evaporator temperature must be low if it is to be used for applications requiring low humidity levels. This results in a lower COP. The process air is then too low for application and must be reheated to the desired levels.

The two basic types of desiccant cooling systems are:

1. *"Standalone" desiccant system.* The process air enters the desiccant section where the moisture is absorbed or adsorbed by the desiccant. This results in warmer, dryer air. The air is then cooled by evaporation to the desired temperature. Two slight variations on this system occur when process air is recirculated or vented.

2. *"Latent-Load Reducer" desiccant system.* This is sometimes referred to as a hybrid system since it combines the components of a vapor-compression system with a desiccant system. This allows the system to meet both sensible and latent cooling loads. The desiccant system removes the latent load while the vapor compressor system meets the sensible load. A combination of heat exchangers and a vapor compression system meets the sensible load requirement. Energy is saved since no overdrying or reheating is required. The vapor compression system required is reduced in size because the latent cooling load is processed under the desiccant system.

Both types of desiccant cooling systems operate on the same physical concepts. The following description of a "standalone" system (Figure 4) is the less complicated of the two types:

1. Process Air Side
   a. *Desiccant Wheel.* The airstream enters the supply air side, and is heated and dehumidified by the desiccant wheel.

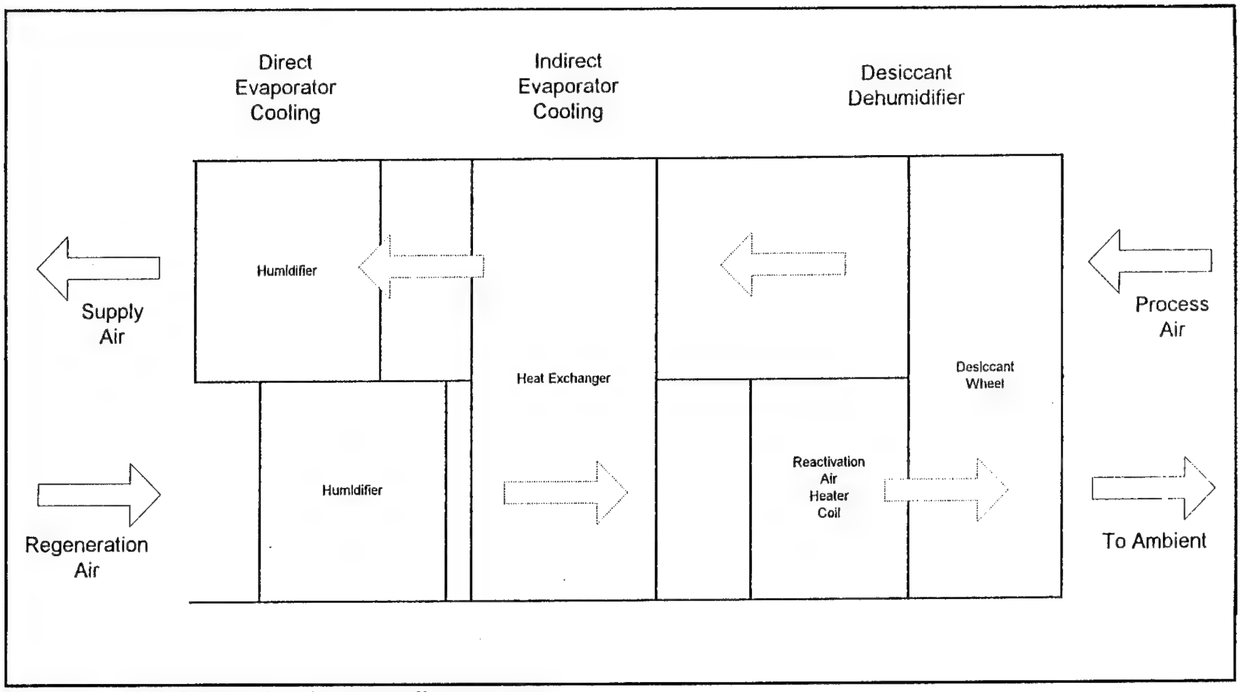

Figure 4. Standalone dessicant cooling system.

b. *Heat Exchanger.* The air leaving the desiccant wheel is further cooled in a heat exchanger. The heat is lost to the air on the regeneration side of the system.

c. *Humidifier.* A second evaporator cooler creates a sensible cooling effect before the air stream discharges to the space.

2. Regeneration Air Side

a. *Humidifier.* The regeneration air is cooled by evaporation and is transferred to the heat exchanger.

b. *Heat Exchanger.* The air from the humidifier is heated by energy transferred from the process air side of the heat exchanger.

c. *Reactivation Air Heater Coil.* The air is further heated to a high enough temperature to reactivate the desiccant in the wheel.

d. *Desiccant Wheel.* The air entering the desiccant wheel is hot enough to remove the moisture from the desiccant, leaving the discharge air cooler and more humid.

The COP for a desiccant system ranges from 0.7 to 1.5. The performance calculation for desiccant systems is not as straightforward as for other systems. Difficulty arises because the desiccant system converts latent load to sensible load; the sensible load must then be removed via heat exchanger and/or an electric vapor-compression system. The electric consumption for process and reactivation fans and for wheel drives must also be considered in the performance calculations.

3 System Characteristics

Background

Equipment information and data used in the feasibility analyses for each site was compiled from electric-driven, gas engine-driven, and absorption chiller and desiccant dehumidifying system manufacturers. The data were curve-fitted or averaged to provide accurate information about the various sizes and types of chillers currently on the market. Specific information included chiller capacity, budget equipment and installation costs, equipment performance, maintenance and operating costs, and the required utility services. This information was constantly updated to reflect current information.

Equipment Capacity

Although electric chiller size categories overlap, small chillers are usually reciprocating; medium chillers are screw-type; and large chillers are centrifugal-type. Overlaps usually occur in the medium to large-size chillers.

Gas engine-driven chillers cover the same capacity ranges as the electric-driven chillers, but are typically limited in the number of available capacities. Advances in this technology are rapidly filling the voids in available capacities. As with the electric-driven chillers, small-capacity chillers are reciprocating, medium capacity are screw-type, and the large-capacity chillers are centrifugal-type.

Absorption chillers are available in a wide variety of capacities and are either direct- or indirect-fired and single- or double-effect. Chillers with capacity greater than 100 tons come in an array of configurations while smaller chillers have somewhat limited configuration options.

Desiccant dehumidifying systems are available in a variety of capacities. Desiccant systems are typically used in buildings with high ventilation air requirements or moisture-control problems.

Budget Equipment and Installation Costs

Budget equipment and installation costs were taken from a variety of manufacturers and reduced to a usable form. No one specific manufacturer is associated with the information. This general information was based on two assumptions: (1) installation costs included only the chiller and not associated equipment, and (2) the installation does not require any rework and is rather straightforward. This information is generic and should be supplemented with any available on-site information.

Capacity and performance are two main considerations in developing cost correlations. Capacity is generally inversely proportional to the unit cost per unit of cooling while performance is proportional to unit cost per unit of cooling. The data represents electric, gas-engine, and absorption chillers and desiccant dehumidifying systems. Since there is a large variation in each application, it is virtually impossible to develop curves representing true installation costs. This data is used for a first-cut estimate of project costs. After review, if implementation of gas cooling technology is found to be cost effective, a detailed budget cost should be developed and a more detailed cost analysis should be performed.

The relationship between capacity and cost may provide an installation an apparently convincing basis for installing a single, large-capacity chiller to meet the load demand (rather than two smaller capacity chillers). Sometimes this approach is cost effective, but this is usually not the case. It is important to consider the fraction of installed capacity at which the chiller plant will typically operate. Chillers are rarely operated at their rated capacities more than a few hundred hours per year. Two or more smaller chillers may result in more efficient operation, lower life-cycle costs, and lower operating costs. In some cases, a hybrid chiller plant makes economic sense. A hybrid plant is a combination of electric- and gas engine-driven chillers and sometimes leads to lower life-cycle and operation costs. The operation of the plants would be cycled to take advantage of the off-demand portion of the electric utility bill. The installation of more than one chiller will also allow for continued service during scheduled and unscheduled maintenance.

Equipment Performance

An analysis of the cost comparison of electric and gas chiller technology must consider the characteristics unique to each of these technologies. The performance of absorption chillers is independent of capacity, but dependent on whether the chiller is steam- or direct-fired, and single- or double-effect. Remember that the boiler efficiency and

parasitic power requirements must be accounted for when calculating economic cost comparison of indirect-fired absorption chillers.

Air-cooled engine-driven chillers usually do not exceed 250 tons in capacity. Water-cooled engine-driven chillers have higher performance ratings, which also come with additional costs. The required cooling tower will cause maintenance and installation costs to rise. This additional cost is usually outweighed by the lower operational cost of these machines. In general, water-cooled equipment should be considered for equipment exceeding 100 tons capacity. This capacity limit will continue to decrease with advances in cooling tower technology. As with absorption technology, it is important to consider parasitic power consumption when performing an economic cost comparison.

Maintenance and Operation Costs

Regularly scheduled maintenance activities are the only way to ensure the proper operation and performance of equipment throughout its useful life. All types of chillers have some maintenance activities in common: required annual checkout and calibration of all controls, regular tube cleaning, periodic check of refrigerant and oil levels and ancillary equipment, and periodic service of the pumps and fans associated with the condensers and evaporators.

In addition to these maintenance activities, absorption chillers require regular checks on the inhibitors. The quality of the refrigerant and absorption fluids must also be checked.

Gas engine-driven chillers require slightly more maintenance. Routine maintenance includes changing oil, oil and air filters, checking belts and fluid levels, changing spark plugs and wires, and adjusting valves, ignition timing, and carburetor settings. Additionally, the engine will periodically require a valve maintenance also referred to as a "top end overhaul." Depending on use and maintenance practices, the engine will require a complete overhaul on a 5- to 10-year (15,000- to 45,000-hour) cycle.

Since most facilities in the United States have electric-driven chillers, personnel are familiar with the maintenance procedures. Introducing gas cooling technology into these facilities will require retraining of personnel or the purchase of maintenance agreements. The cost of these agreements are usually a function of the chiller capacity. These agreements are not exclusive to gas engine-driven chillers and can be purchased for electric-driven chillers as well.

As expected, the maintenance cost of gas engine-driven chillers is somewhat more expensive than that of an electric-driven or absorption chiller or desiccant dehumidifying systems. Annual maintenance costs are estimated knowing the annual equivalent full load hours of operation, maintenance costs, and chiller capacity. The maintenance cost of gas engine-driven chillers are approximately 1.5 to three times higher than their electric counterparts with the cost of absorption units and desiccant dehumidifying systems falling somewhere in between.

Water-cooled chillers require purchasing, treating, and disposing of water. Generally the make-up water requirements for an electric-driven chiller are lower than for its gas cooling technology counterparts. The cost of make-up water (gal/t-h*) for an absorption chiller is 50 to 60 percent more than for the electric chiller. A 10-percent increase is required for a gas engine-driven chiller. This is based on the required maintenance and treatment of make-up water and the required quantity of water for each type of technology,

Economic Evaluation

The data discussed in the previous sections are used as inputs to an evaluation spreadsheet. Some site-specific information is required to complete the spreadsheet. Additional information includes utility rates, cooling loads, and (if heat recovery from an engine-driven chiller is being considered) boiler efficiency. Spreadsheet output summarizes the economic results and indicates the relative costs and benefits of each cooling technology. An accompanying breakdown of annual operating costs for each technology includes the cost of natural gas, electric energy and demand, maintenance, and make-up water. A sample spreadsheet is included in Appendix A.

* 1 gal = 3.78 L; 1 ton = 907.185 kg.

4 Environmental Issues

DOD Fixed Facility Energy Consumption

The Defense Energy Information System (DEIS) was commissioned to obtain energy consumption, inventory, and cost data from each of the services. DEIS tracks all purchased and nonpurchased energy consumption (excluding nuclear energy). The major commands use this information to evaluate trends and determine progress toward meeting energy reduction goals. All three branches of the Armed Services consume approximately the same amount of energy for their fixed facilities. The proportion of fuel types are roughly the same with the Air Force being the exception. The Air Force consumes more natural gas and less fuel oil than the other two services. Using the 1985 data as a baseline, all services have reduced overall energy consumption. However, all three services have increased the amount of electricity consumed, which has lead to an increase in energy costs. Natural gas consumption has remained relatively stable. Most of the energy the services consume is made up of natural gas and electricity.

DOD Fixed Facility Energy Costs

Nearly equal amounts of natural gas and electricity are consumed at the facilities by each of the services. Electricity costs account for nearly 70 percent of the total facility costs while natural gas accounts for less than 20 percent. In fact, electricity costs over four times more than natural gas on a "per unit of energy" basis. Clearly, other less expensive options should be considered with electricity when available. The use of new natural gas technologies could reduce DOD operating costs by increasing the efficiency of existing gas systems, converting more expensive fuel technologies to natural gas, applying overall new technologies, and developing electrical generation capabilities. In contrast to expectations, energy costs are escalating despite successful energy conservation efforts. Fuel costs are actually only one part of the overall cost associated with implementing new technology in DOD facilities. All economic analysis must be made on life-cycle cost basis including capital equipment investments and operations and maintenance costs.

Environmental Impact of Gas Cooling Technology

Several environmental issues must be discussed when evaluating any new or existing cooling technology. The most obvious is the impact of refrigerants on the ozone layer. The impact of natural gas combustion products, in particular carbon dioxide (CO_2), on global warming is of equal concern, but usually does not receive as much attention.

Some believe the release of chlorofluorocarbons (CFCs) is a major contributor to the destruction of the ozone layer located in the stratospheric region of the atmosphere. As these molecules make their way to the stratosphere, they deplete ozone (O_3) through a catalytic reaction. This concern has led to a congressional mandate to eliminate the use of CFCs, particularly in chiller applications. New chillers are usually shipped with either hydrochlorofluorocarbons (HCFCs), which have a significantly lower ozone depletion potential, or hydrofluorocarbons (HFCs), which have a zero ozone depletion potential. However, a large portion of existing chillers are still charged with CFCs; the problems associated with these units persist.

Solar radiation penetrates the earth's atmosphere daily, heating it to a given level. This energy is reradiated back into the atmosphere thereby creating a cooling effect. Equilibrium between these two modes of energy transfer allows earth to remain habitable. Various factors contribute to the rate at which this energy is radiated and reradiated through the earth's atmosphere. Much research has been conducted in this process.

In recent years, some scientists have come to believe that an imbalance between these energy transfer modes is causing the earth to warm. They believe this warming effect is caused by an increase of CO_2 in the atmosphere produced by combustion processes, including those associated with the internal combustion engine, various manufacturing processes, and processes used for the generation of electricity. The release of refrigerants in the atmosphere is also thought to contribute to this warming effect. This presumed temperature increase in the earth's atmosphere has been named, by scientists and politicians alike, the "Greenhouse Effect."

Alternative Refrigerants

The ozone depletion and global warming concerns has changed the criteria used in the selection of refrigerants. At one time, refrigerants were selected based on their thermodynamic properties, flammability limits, toxicity levels, molecular stability, and cost. Recent environmental concerns have added considerations associated with a refrigerant's ozone depletion potential and global warming potential to the list of

selection criteria. Since significant strides have been made in developing and implementing refrigerants with zero ozone depletion potential, this study did not address this issue.

Global warming is a complex problem, and one for which a solution cannot be easily determined. Because of this, a Total Equivalent Warming Impact (TEWI) has been developed and can be calculated for each type of cooling technology. These values can also be used to help determine the cooling technology most appropriate for a given site. The TEWI is the sum of the Equivalent Warming Impact from direct effects and the Equivalent Warming Impact from indirect effects. Direct effects are those attributed to the intentional or unintentional leakage of refrigerants that have nonzero global warming potential. Indirect effects are those associated with the combustion of fossil fuels to drive the chiller and its auxiliary components. The determination of the TEWI value for the available cooling technologies, along with sample calculations, are detailed in a separate USACERL technical report (Cler 1995).

5 Sites

The initial screening of sites from task 1 (cf. p 6) identified a number of Army, Navy, and Air Force sites where gas cooling technologies could be considered for replacement of failed or failing chillers. System installations at these sites were found to be technologically and economically viable solutions to existing problems. A technologically viable solution was one that resulted in a system that was capable of providing the necessary cooling capacity for the given scenario. An economically viable solution was based on the incremental cost differential between the gas cooling option and an electric-driven chiller. The projects are in various phases of execution and each project will be discussed separately.

Fort Eustis

Technology screening for Building 2716 and the McDonald Hospital reveal both to be gas cooling technology candidates. It is proposed that the 100-ton electric-driven chiller in Building 2716 be replaced by a gas engine-driven chiller of comparable size. A simple payback of 4.3 is estimated. An evaluation for the hospital will be completed once additional site information is obtained. A work plan may be developed if other project issues are resolved.

Fort Hamilton, NY

The first of two projects at Fort Hamilton is the replacement of a 50 and a 60-ton barracks chiller. It was desirable to replace the 50-60 combination with a single chiller unit. A single 125-ton gas engine-driven chiller was proposed for the barracks. Cost estimates predict an immediate payback for this system since the rebate offered by the gas and electric utility is enough to lower the cost below that of an electric drive system. Thus gas technology is highly desirable in this situation. A heat recovery system is also being considered which will yield even greater savings if installed. The second project involves replacing an existing air-cooled 25-ton, direct expansion rooftop air-conditioning unit located on the roof of a day care. The replacement unit will be a gas engine-driven chiller. The higher "$/ton" cost of small capacity units extends the simple payback of this project to less than 3 years with a Savings-to-Investment ratio

(SIR) of 5.3. As with other gas engine-driven units, the annual operating costs are predicted to be significantly lower than their electric-drive counterparts. The designs for this project are complete with the associated construction and contracting documents currently under development.

Fort Huachuca, AZ

Fort Huachuca had three facilities that were evaluated for gas cooling projects. Electric, direct-fired, and indirect-fired replacement units were evaluated using life-cycle cost analysis. Of the three facilities, the hospital was determined to have the most potential for an economically successful project. It was cooled using two, 25-year-old, CFC-based, 128-ton electric-driven chillers. These chillers, which could not meet peak demand, were replaced with two, 150-ton, two-stage, steam-fired absorption chillers. An auxiliary structure had to be built to house the absorption units since the existing mechanical room was already overcrowded. The new construction, though costly, freed some much needed space in the mechanical room. There were two existing cooling towers. The older of the two requires much repair and is to be replaced as part of this project. The simple payback on this project was calculated to be less than 3 years based on the costs of construction, annual energy savings, and operation and maintenance.

Fort Jackson, SC

Fort Jackson was planning a major renovation of its energy plants. The cooling equipment consisted of a 400-ton CFC-11 plant and a 750-ton, single-stage absorption unit. Both of these units were nearing the end of their useful lives. This existing system was unable to meet the cooling loads during the hottest summer months. An economic analysis based on the energy consumption data provided by the base showed a significant savings could be achieved by replacing the existing units. Some recent improvements in cooling tower, pumps and piping allowed larger cooling systems to be installed without requiring any modifications to these systems.

The feasibility study considered electric-driven chillers, natural gas-driven chillers, and two-stage, direct-fired absorption chillers. Replacement with electric-driven chillers would be cost prohibitive since the existing electric service would have necessitated an upgrade. The local utility also provided an additional incentive giving a $100/kW rebate to customers who installed gas chiller options over electric. The domestic hot water service obtained from the heat ejected by the engine exhaust and water jacket and the high COP of the gas engine-driven chiller made it the most

desirable system over the electric-driven and absorption units. A pair of 700-ton gas-driven chillers were installed with a simple payback estimated to be less than 4 years.

Fort Riley, KS

The energy plant located at the Irwin Medical Center consisted of steam boilers, steam-driven and electric-driven centrifugal chillers, and the distribution system for the hospital and three additional buildings. The cooling system consisted of three, 200-ton, steam-driven centrifugal chillers and two, 485-ton chillers—all of which use CFC-based refrigerants. The total capacity and existing elevated cooling towers were adequate so only the aging 200-ton chillers were considered for replacement.

Feasibility studies evaluated electric-driven, gas engine-driven, and two-stage steam and direct-fired absorption chillers as replacement. Required upgrades in the electric service made the electric units cost prohibitive. Even without rebates, two, 350-ton HCFC-22, gas engine-driven chillers were deemed the most economically beneficial to the facility. The heat recovery system was used to help provide domestic hot water and preheated boiler feed water. The system was successfully installed. A complete data acquisition system to monitor the chiller performance has been installed with only a few wiring and calibration details requiring attention. The details of the monitoring system can be reviewed in Appendix B. The estimated discounted payback was just under 9 years.

Naval Air Station Willow Grove, PA

Willow Grove has one of the highest demand rates in the nation. In addition to the high demand rate, it has a ratchet penalty that causes payment of electrical energy not used or needed 8 months of the year. This makes the facility a prime candidate for installation of gas cooling technologies. NAS Willow Grove presently has two, 15-ton, Thermo King, natural gas engine-driven rooftop heating/cooling units that were installed at the Navy Exchange in 1992. This first test bed demonstration resulted from a Cooperative Research and Development Agreement (CRADA) between the Department of Energy (DOE), Thermo King Corporation, the Naval Air Station, the Philadelphia Electric Company, and the American Gas Cooling Center. Pacific Northwest Laboratory managed the project for DOE. The results from data collected during the 1992 cooling season revealed cost savings of $4,100, electric demand ratchet savings of $8,850, and energy savings of 7.5 MBtu.

In 1993, Willow Grove installed a 25-ton, engine-driven, split system chiller and a 80-ton, engine-driven chiller. Both installations will reduce CFC use and result in approximately $18,000 in cost savings per year. Actual cost savings were not available at the time of this writing.

Presently USACERL and NFESC are cooperatively working on a desiccant and direct-fired, double-effect absorption chiller project at Building 180–Aircraft Intermediate Maintenance Department (AIMD). An 80-ton, direct-fired, double-effect absorption chiller and a 30,000 cfm* two-wheel desiccant system will replace the existing Centrifugal CFC-11 chiller and provide chilled water and humidity control for the administrative space and part of the maintenance area. Actual cost savings were not available at the time of this writing, but eliminating supercooling and reheating to reduce humidity, combined with cooling by natural gas, should result in significant energy and monetary savings.

On completion of the AIMD project, NAS Willow Grove will have every type of commercially available natural gas cooling technology. For this reason and the fact that Willow Grove has the highest demand rates in the nations, it has been selected as the Navy's showcase site for natural gas cooling technologies.

Naval Training Center, Great Lakes, IL

The Naval Hospital located at the Naval Training Center was served by two aging 175-ton, single-effect, steam absorption chillers and a cooling tower. These chillers have been replaced with two, natural gas direct-fired, double-effect absorption chillers of the same capacities and an adequately sized cooling tower. Due to the facility's function and operating hours, various levels of cooling are required continuously throughout the summer and occasionally during the winter months. The construction contract was awarded in November 1994 and equipment installation was completed in November 1995. NFESC has completed approximately 60 percent of the monitoring equipment installation and is awaiting final equipment installation to be completed by station personnel. The monitoring system should be operational by late January 1996. CFC use will not be reduced by this project, but the estimated discounted payback was just under 4 years

The Naval Training Center also has many large centrifugal chillers throughout the base. In an effort to reduce the use of CFC cooling equipment, the NTC has become very active in the demonstration of natural gas cooling technology. The Administra-

* 1 cu ft = 0.028 m^3.

tion Building, Building 1405, is the second natural gas cooling demonstration site at the Naval Training Center. The multi-story administration building is cooled with a 400-ton centrifugal chiller using CFC-12. The preferred replacement is a 400-ton, direct-fired, double-effect absorption chiller. Through an existing A/E Contractor, NTC and NFESC have completed the design submission. FY94 Office of Chief of Naval Operations (OPN) funds were sent to NTC in November 1995. Award of a construction contract is expected by 31 January 1996. To assist in the economic attractiveness of the project, the North Shore Gas Company has offered a rebate of $200/ton for the first 150 tons and $50 for each additional ton. The estimated cost savings is $8,495/year and the addition of the rebate program resulting in a simple payback of less than 6 years.

Naval Medical Center, Bethesda, MD

Two, 500-ton, steam-fired absorption chillers have been replaced with a single, 1000-ton, dual-fuel (Natural Gas/Fuel Oil), direct-fired, double-effect absorption chiller. The existing chillers are inefficient and require continuous maintenance. The 1000-ton chiller when brought on-line will be one of seven chillers resulting in 7220 tons of cooling capacity. The chiller will run during peak electrical demand periods with additional cooling provided by electric-driven chillers. The chiller will be connected to the existing cooling tower, which provides condenser water for all the chillers. The chilled water plant will operate to maximize monetary savings.

Similar to the Naval Hospital in Great Lakes, the Naval Medical Center requires various levels of cooling year round and reliability of the cooling equipment is essential to the facility's mission. The construction contract was awarded in April 1994. The chiller has been installed, but testing has been delayed due to electrical wiring problems. The chiller is expected to be brought on-line by late January 1996. CFC use will not be reduced by implementing this project, but the estimated discounted payback is just under 4 years

Marine Corps Air Station, Yuma, AZ

The 25-year-old, 283-ton centrifugal chiller using CFC-11 and a cooling tower are in the process of being replaced with a 300-ton, direct-fired, double-effect absorption chiller and a new cooling tower. The chiller will provide cooling to three barracks and a lounge area. The existing chiller was operational, but required constant maintenance to provide cooling for the three barracks. The chiller was also undersized and did not provide adequate cooling. The replacement chiller will provide sufficient

cooling for the barracks and reduce CFC use at the Air Station. The chiller is expected to be installed and fully operational by late January 1996. Monitoring equipment is approximately 60 percent installed and awaits completion of cooling equipment for project completion. Estimated discounted payback is just under 9 years.

Submarine Base, New London, CT

The Bachelor Officers Quarters, Building 488, at Submarine Base New London, is presently being cooled with a 13-year-old, 175-ton, CFC-11 centrifugal chiller and a cooling tower. The existing chiller will be replaced with a 175-ton, direct-fired, double-effect absorption chiller and a new cooling tower. Selection of Submarine Base New London was based on the excessively high electric demand rate used by the utility company ($27.50 /kW) and the need to reduce CFC refrigerant use at the base. An A/E contractor has completed the design submission. FY94 OPN funds were received by NFESC in November 95 and have been sent to New London to award the contract. The estimated cost savings is approximately $16,000/year resulting in a simple payback just over 4 years.

Fleet Combat Training Center, Damneck, VA

The Naval Guided Missile School, Building 543, has recently undergone building modifications to increase its energy efficiency. The HVAC system (i.e., air handlers, duct work, cooling tower, etc.) has been upgraded and a new digital control system has been added to control the HVAC system. Building modifications (e.g., insulation and new windows) have decreased the needed cooling capacity for the building and a new cooling tower. The project will replace the 260-ton, CFC-11 centrifugal chiller, which is the only old component remaining on the new HVAC system, with a 210-ton, direct-fired, double-effect absorption chiller. The design has been completed and funds have been received to award the contract. Virginia Natural Gas has offered a $50/ton rebate and an incentive of 20 percent of the energy saved by converting to natural gas. By replacing the existing chiller with a natural gas absorption chiller and benefiting from the gas utility company rebate and incentive program, the base can save approximately $5,900/year. The project shows a potential simple payback of just under 7 years.

Naval Education and Training Center, Newport, RI

The Naval Education and Training Center Officer's Club, Building 95, has a maximum cooling capacity of 120 tons. The existing centrifugal chiller (CFC-12) and cooling tower are approximately 11 years old and will be replaced with a direct-fired, double-effect, absorption chiller of the same capacity and an adequately sized cooling tower. The project design has been completed and FY94 OPN funds have been received. Providence Gas Company has offered a $200/ton rebate for the installation of natural gas cooling equipment. The rebate combined with the Officers Club cooling requirements during on- and off-peak times, and an 11-month demand ratchet results in an attractive cost effective project. The estimated cost savings is $10,350/year. The resulting potential simple payback is less than 3 years.

Naval Air Station, Miramar, CA

Building 515, which functions as the Electronics/Hydraulics Maintenance Training Facility, has been without permanent cooling for the past year. The facility rented a chiller at $6,000/month to provide the necessary cooling capacity. The existing HVAC system will be outfitted with a 150-ton, natural gas absorption chiller and adequately sized cooling tower to replace the rented centrifugal chiller and old cooling tower. The Naval Air Station project was funded with FY93 OPN funds to expedite the installation of the chiller. Presently, the chiller and ancillary equipment has been received, but contractual problems have slowed the installation. Monitoring equipment for this site is 60 percent complete and awaits chiller installation to be fully functional. The estimated cost savings is $8,120/year, with a potential simple payback slightly less than 8 years.

Columbus Air Force Base, OH

The T34/T38 training facility at the Columbus AFB (CAFB) currently is cooled by two, 329-ton, CFC-12 chillers, each of which can provide enough cooling to handle the design day load by itself. Failure to provide the necessary cooling will render the facility useless and result in costly delays in pilot training. A feasibility analysis was conducted based on data obtained 11 September 1995. It was determined that the replacement of the worse of the electric chillers with a gas engine-driven chiller will give CAFB greater resource capability and reduce the cost of cooling. A 250-ton, gas engine-driven chiller was selected to replace one aging electric-driven chiller. The favorable 1:6 per unit cost of gas to electricity ratio and a high demand charge makes

installation of a gas engine-driven chiller even more attractive. An incremental SIR is 5.0 with a depreciated payback period of 3 years. This project is in design.

Davis-Mothan Air Force Base, AZ

Davis-Mothan AFB (DMAFB) currently has a 23-year-old, 400-ton gas engine-driven chiller and a 24-year-old, 400-ton, electric-driven chiller at a facility where the peak cooling load is estimated at 350 tons. The installation desires to replace the electric unit with a gas engine-driven chiller. During the summer of 1994, the gas engine-driven chiller experienced a bearing failure. The backup electric-driven chiller was brought up to speed and consumed an estimated $25k in demand charges before the gas engine-driven was repaired. Assuming one of the chillers would be replaced to become the primary cooling provider, an analysis was conducted comparing an electric-driven chiller to a gas engine-driven chiller and a gas-fired absorption chiller.

It was determined that, even ignoring heat recovery opportunities, installing a gas chiller would have a payback of 4.3 to 5.6 years. The opportunity to replace a 250-ton, CFC-11 chiller at the DMAFB hospital with a gas engine-driven chiller also exists. The plant was assumed to have approximately 2200 Effective Full Load (EFL) hours of cooling for a 12-month period. A feasibility study similar to the previous one resulted in a gas engine-driven chiller being more favorable with a payback of the incremental investment in 4.5 to 5.6 years. Pending final approval, a design for a new engine chiller at the central cooling plant will proceed.

Tinker Air Force Base, OK

Tinker AFB is installing direct-fired, double-effect absorption units as replacement units for three existing steam turbine-driven chillers in Building 3001. This facility supports the energy requirements for depot industrial operations, a computer center, and administrative space. The plant had eight, 1500-ton, steam turbine-driven chillers for a total capacity of 12,000 tons. Due to a reduction in required capacity, the new chillers will be rated at 1000 tons. The existing auxiliary structures will require minimal changes. Commissioning the new system will include technical support from USACERL and will occur in FY96 and FY97.

Warner-Robins Air Force Base, GA

Several construction projects are being undertaken at Warner-Robins Air Force Base's (WRAFB's) central facilities. A proposal to install two, 1500-ton, gas engine-driven chillers is being pursued. WRAFB will fund a large portion of the plant modifications to support the new chillers. Design is expected to commence the second quarter of FY96 and construction to start the first quarter of FY97.

Wright-Patterson Air Force Base, OH

A site visit was conducted at Wright-Patterson AFB hospital in October 1995. The hospital appears to be a good candidate for a hybrid electric and gas engine-driven cooling application. The existing facility has three chillers, of which only two can operate due to electrical feeder limits. The Air Force has been provided with the various options afforded to them by implementing the hybrid configuration and the associated construction factors. A design will not be pursued in FY96.

6 Summary and Recommendations

Summary

This study has detailed and evaluated existing gas cooling technologies and their applications to DOD fixed facilities. These technologies include absorption, gas engine-driven, and desiccant chillers. The thermodynamic cycles of each type were discussed individually and the expected COP for each was given. The benefits of installing gas cooling technologies at DOD fixed facilities range from reducing total electric consumption, which can dramatically reduce energy costs associated with peak demands, to lessening the adverse impact on the environment typically associated with chillers.

This evaluation was conducted by first determining the facilities that could benefit the most by introducing high technology gas cooling chillers as part of a remodeling, replacement, or expansion project. This study also investigated potential implementation sites, developed the equipment purchase documentation, supervised the equipment installation and acceptance, monitored equipment performance, and documented "lessons learned" in as much detail as funding allowed.

A description of each system provided better insight into the capacity, performance, maintenance, and operation costs and economical aspects of each. This wide array of system characteristics made it impossible to select the type of chiller best suited for any one facility without performing a first-cut economic and feasibility analysis. Data for this analysis was taken from current manufacturer's information and reduced to a usable form. This information was then fed into an USACERL-developed spreadsheet, which produced the expected payoff and payback information.

Finally, a list of DOD facilities that were evaluated in the feasibility analysis were discussed and the current status of each project documented. These sites have been divided into the individual branches of the Armed Services: the Army, Air Force, and Navy (Marines included). Army and Air Force projects are under the supervision of a principal investigator at USACERL; Navy projects are under the supervision by the NFESC. This study was done with the close coordination and collaboration of USACERL, NFESC, and AFCESA.

In general, the gas cooling technologies implemented at DOD fixed facilities in this study appear to be performing as anticipated. This includes posting the predicted economic benefits and meeting the load expectations at each base. While gas cooling chillers may not be the "cure-all" solution for every facility and every application, they are a viable option to electric-driven chillers.

Recommendations

Any facility requiring a replacement of existing inefficient equipment, replacement of inoperable equipment, or expansion in capacity should consider the use of gas cooling technologies. If this technology is installed, it is also recommended that these facilities be monitored for performance by USACERL representatives to document the actual savings incurred.

To achieve the full benefit of gas cooling technology, it is recommended that documentation of the following procedures be developed:

1. *Standard Procurement Procedures* to assist an installation in the purchase of new gas cooling technologies. Sometimes additional equipment (cooling towers, pumps, etc.) is required as part of a new procurement. These items must be identified early in the procurement process to avoid unnecessary and costly delays.

2. *Operation and Maintenance Procedures* to ensure longevity of the new equipment. It is particularly important to properly maintain gas engine-driven chillers. Improper maintenance procedures can result in premature engine failure and costly overhauls.

3. *Commissioning Procedures* to guarantee proper installation and setup of a new system. Without these procedures, improper installations can occur. This can lead to equipment failures and lower than expected performance, which will increase the estimated payback period.

4. *Integrated Operating Procedures* to ensure the facility maximizes the new system's potential. Since new systems are usually installed as part of an existing plant, it is important for plant operators to know how the new system's operation relates to the operation of the existing units in the facility. Operation outside of a unit's (or entire plant's) design will result in longer payback periods and possible increases in utility costs.

This documentation will be site specific and should be produced by people with intimate knowledge of the equipment, of the equipment's overall intended operation, and of the operation of the existing facility. However, the simple creation of the documentation will not ensure optimal installation and operation of new systems; the outlined procedures must be followed. If necessary, proper training must be administered to ensure that the procedures are followed.

Appendix A: Gas Cooling Analysis Spreadsheet

Gas Cooling Analysis

Input Data Sheet

< To Print Tables - ctrl t, To Print Charts - ctrl c >

Notice to Users:

This spreadsheet is designed to assist the user in performing a preliminary feasibility analysis comparing electric, absorption, and engine driven chillers. Calculations are based on user provided data and results rely on this input data. This spreadsheet calculates the approximate equipment & installation costs along with the annual operating and maintenance costs. Additionally, simple payback is calculated, based on the incremental additional cost of the alternative cooling technology and the annual operating cost savings.

Input Section

Fill in all shaded boxes

Enter Facility Name: Wright-Patterson AFB, Med Center

Analyst: MKB 6/1/95

Cooling Load

Building Type: Hospital 1 new electric

Peak Load:	1,200	tons
Annual Hours of Operation:	8,760	hours
Equivalent Full Load Hour Percentage:	85	% (for most air conditioning applications, EFLH = 50 %)

Cooling Peak Load/Ave Load Ratio: 1.18

Chiller Efficiencies:	Peak	IPLV	COP Ratio		Parasitic Electrical Requirements:		
Existing Electric (kW/ton)	0.71	0.71			Existing Elect	0.235	kw/tn
New Electric (kW/ton)	0.55	0.55	1.30	New/Old Ele	New Elect	0.235	kw/tn
Absorption (COP)	1.00	1.00	0.16	Abs/New Elc	Absorption	0.310	kw/tn
Engine Driven (COP)	1.90	1.95	0.30	Gas/New Elc	Eng Driven	0.250	kw/tn

Monthly Peak Cooling Load (% of peak)

Jan	80	Feb	100	Mar	100	Apr	100
May	100	Jun	90	Jul	90	Aug	90
Sep	100	Oct	100	Nov	80	Dec	80

Notes: 1 therm = 100,000 Btu; k = 1000 (kW = 1000 W); M = 1,000,000 (MBtu = 1,000,000 Btu)
When evaluating steam fired absorption chillers, be sure to account for boiler efficiency when entering chiller COP. This is not done automatically.

Gas Cooling Analysis

Input Data Sheet

Facility: Wright-Patterson AFB, Med Center

Utility Rates

Notes:
Cent Water Cooled Units (NG and Elect)
Actual Old kw/tn available

Engine waste heat considers both exhaust gases and cooling jacket water
If boiler fuel not gas, convert $/MBtu to $/therm
Can not calculate winter type ratchet charges; input directly??
Must use month format Xxx (i.e Jan, Feb)

Natural Gas Utility Rates:

Cooling Rate	0.428	$/therm
Boiler Rate	0.428	$/therm
Elect/Gas Use Cost Ratio	1.37	

Electric Utility Rates:

Summer Demand	12.31	$/kW	from	Mar	through	Sep
Ratchet	75	%	from	Jan	through	Dec
Winter Demand	12.31	$/kW	Demand$/Use$ Ratio (hrs)			
Energy	0.020	$/kWh	Smr. El/Gas:	843	Wntr El/Gas:	843

NOTE: Review demand charge calculations to determine appropriate values to enter for number of applicable months.

NOTE: The above rates should include any applicable taxes and surcharges.

Equipment Cost

	Chiller $/ton	Rebate $/ton	Installation $/ton	Maintenance	
Electric (existing)				0.008	$/ton-hr
Electric (new)	280	0	270	0.006	$/ton-hr
Absorption	450	0	290	0.0085	$/ton-hr
Engine Driven					
w/o heat recovery	500	100	275	0.012	$/ton-hr
w/ heat recovery	510	100	285	0.013	$/ton-hr

Heat Recovery

(Engine Driven Chiller only)

Useful thermal energy	2,600,000	Btu/hr
Summer boiler efficiency	80	%

Engine Waste Heat

Engine efficiency	35	%
Recoverable percent	75	%
Max avail thermal energy	3,600,000	Btu/hr

Gas Cooling Analysis

Output Data Sheet

Facility: Wright-Patterson AFB, Med Center

Existing Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.714 kW/ton
Chiller IPLV (seasonal efficiency): 0.714 kW/ton (see note below)

Energy Charge (chiller):	1,200 tons	x	0.714 kW/ton (IPLV)	x	7,446 EFLH	x	0.020 $/kWh	= $127,595
Energy Charge (parasitic):	1,200 tons	x	0.235 kW/ton	x	8,760 operating h	x	0.020 $/kWh	= $49,406
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)							= $155,632
							Total Annual Energy Cost	**$332,633**

New Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.55 kW/ton
Chiller IPLV (seasonal efficiency): 0.55 kW/ton (see note below)

Energy Charge (chiller):	1,200 tons	x	0.550 kW/ton (IPLV)	x	7,446 EFLH	x	0.020 $/kWh	= $98,287
Energy Charge (parasitic):	1,200 tons	x	0.235 kW/ton	x	8,760 operating h	x	0.020 $/kWh	$49,406
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)							= $128,737
							Total Annual Energy Cost	**$276,430**

Absorption Chiller Energy Costs

Chiller Peak Efficiency: 1.00 COP
Chiller IPLV (seasonal efficiency): 1.00 COP -or- 0.120 therms/ton-hr (see note below)
Incremental Parasitic Power Consumption: 0.31 kW/ton (see note below)

Gas Charge:	1,200 tons	x	0.120 therms/ton-hr	x	7,446 EFLH	x	0.428 $/therm	= $458,912
Energy Charge (parasitic):	1,200 tons	x	0.310 kW/ton	x	8,760 operating h	x	0.020 $/kWh	= $65,174
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)							= $54,961
							Total Annual Energy Cost	**$579,047**

Engine Driven Chiller Energy Costs

Chiller Peak Efficiency: 1.90 COP
Chiller IPLV (seasonal efficiency): 1.95 COP -or- 0.062 therms/ton-hr (see note below)
Incremental Parasitic Power Consumption: 0.25 kW/ton (see note below)
Heat Recovery: 2,600,000 BTU/hr
Boiler Efficiency: 80%

Gas Charge:	1,200 tons	x	0.062 therms/ton-hr	x	7,446 EFLH	x	0.428 $/therm	= $235,339
Energy Charge (parasitic):	1,200 tons	x	0.250 kW/ton	x	8,760 operating h	x	0.020 $/kWh	= $52,560
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)							= $44,323
							Total Annual Energy Cost (without heat recovery)	**$332,223**
Savings with Optional Heat Recovery:	2,600,000 Btu/hr	x	1 therm/100,000 B	x	7,446 EFLH	x	0.428 $/therm / 80 % boiler efficiency	= ($103,574)
							Total Annual Energy Cost (with heat recovery)	**$228,649**

EFLH = Equivalent Full Load Hours (for most air conditioning applications, EFLH = 0.5 x annual hours of operation)
IPLV = Integrated Part Load Value. The IPLV should be used for all seasonal energy calculations, since is it represents the seasonal average (non-full load) operating efficiency of the chiller.
therms/ton*hr = 12,000 Btu/hr/ton / (100,000 Btu/therm x COP [Btu/hr Cooling / Btu/hr Input])
Direct-fired absorption chillers have significantly higher electric parasitic consumption than electric chillers. This is due to greater condenser flow rates, heat rejection, and pressure drops in the heat exchangers. Engine driven chillers have slightly higher parasitics than electric chillers due to the engine heat rejection.

Gas Cooling Analysis

Output Data Sheet

Facility: Wright-Patterson AFB, Med Center

Month	Demand Charge ($/kW)	Existing Electric Chiller Billed Demand (kW)	Existing Electric Chiller Monthly Charge ($)	New Electric Chiller Billed Demand (kW)	New Electric Chiller Monthly Charge ($)	Absorption Chiller Billed Demand (kW)	Absorption Chiller Monthly Charge ($)	Engine Driven Chiller Billed Demand (kW)	Engine Driven Chiller Monthly Charge ($)
Jan	12.312	911	11,217	754	9,278	372	4,580	300	3,694
Feb	12.312	1,139	14,021	942	11,598	372	4,580	300	3,694
Mar	12.312	1,139	14,021	942	11,598	372	4,580	300	3,694
Apr	12.312	1,139	14,021	942	11,598	372	4,580	300	3,694
May	12.312	1,139	14,021	942	11,598	372	4,580	300	3,694
Jun	12.312	1,025	12,619	848	10,438	372	4,580	300	3,694
Jul	12.312	1,025	12,619	848	10,438	372	4,580	300	3,694
Aug	12.312	1,025	12,619	848	10,438	372	4,580	300	3,694
Sep	12.312	1,139	14,021	942	11,598	372	4,580	300	3,694
Oct	12.312	1,139	14,021	942	11,598	372	4,580	300	3,694
Nov	12.312	911	11,217	754	9,278	372	4,580	300	3,694
Dec	12.312	911	11,217	754	9,278	372	4,580	300	3,694
Ave/Sum		1,053	155,632	871	128,737	372	54,961	300	44,323

Monthly Demand Charge ($/kW) is determined from the utility rate structure or utility contract.
Billed Demand ($) is calculated based on the utility rate structure. If there is no Ratchet associated with the demand charge, the Billed Demand equals the peak metered demand which occured during that month.
If the utility rate structure has a Ratchet clause, the Billed Demand is equal to the greater of either the actual peak metered demand or the peak demand multiplied by the Ratchet percentage.
Monthly Charge ($) is calculated by multiplying the Monthly Demand Charge by the Billed Demand.
The Annual Average/Sum is the average of the monthly Billed Demands and the sum of the Monthly Demand Charges for each of the chiller technologies.
The actual meter demand is the sum of the peak output of the chiller during the month in question plus the full KW rating of the parasitic equipment, i.e. the evaporator and condenser water pumps and cooling tower fan motors.

Gas Cooling Analysis

Output Data Sheet

Facility: Wright-Patterson AFB, Med Center

Maintenance Costs

	EFLH		Capacity		Rate		Maintenance Costs	Annual Operating Costs (Energy + Maintenance)
Electric Chiller Maintenance Costs								
Existing	7446 EFLH	x	1200 tons	x	0.008 $/ton-hr	=	$71,482	**$404,115**
New	7446 EFLH	x	1200 tons	x	0.006 $/ton-hr	=	$53,611	**$330,042**
Absorption Chiller Maintenance Costs								
	7446 EFLH	x	1200 tons	x	0.0085 $/ton-hr		$75,949	**$654,996**
Engine Driven Chiller Maintenance Costs								
w/o heat recovery	7446 EFLH	x	1200 tons	x	0.012 $/ton-hr		$107,222	**$439,445**
w/ heat recovery	7446 EFLH	x	1200 tons	x	0.013 $/ton-hr		$116,158	**$344,806**

System Installed Cost

	Equipment Cost			+	Installation Cost			=	Installed Cost	Utility Rebate	Cost Premium	Incremental Simple Payback
Electric Chiller Installed Costs												
	280 $/ton	x	1200 tons	+	270 $/ton	x	1200 tons	=	$660,000		$0	**basecase**
Absorption Chiller Installed Costs												
	450 $/ton	x	1200 tons	+	290 $/ton	x	1200 tons	=	$888,000		$228,000	**NEVER**
Engine Driven Chiller Installed Costs												
w/o heat recovery	500 $/ton	x	1200 tons	+	275 $/ton	x	1200 tons	=	$930,000	$120,000	$150,000	**NEVER**
w/ heat recovery	510 $/ton	x	1200 tons	+	285 $/ton	x	1200 tons	=	$954,000	$120,000	$174,000	**NEVER**

Annual Operating Cost = Annual Energy Cost + Annual Maintenance Cost
Installed Cost = Chiller Cost per Ton * Capacity + Installation Cost per Ton * Chiller Capacity
Cost Premium = Installed cost of a specific chiller type - installed cost of an electric chiller
Incremental Simple Payback = Cost Premium/(Electric Chiller Annual Operating Cost - Specific Chiller Annual Operating Cost)

Appendix B: Engine-Driven Chiller Data Acquisition System for the Irwin Army Hospital at Fort Riley, KS

Objective

The objective of this project is to develop comprehensive data collection and analysis procedures to provide accurate and thorough data for input to feasibility studies for the replacement of existing cooling technologies with natural gas cooling technologies. The first step is to perform an extensive study of the required input data elements, making sure that important parameters are not being overlooked and that inconsequential ones are not included. The cooling load profile, outdoor temperature and relative humidity, fuel costs, maintenance costs, the chiller's coefficient of performance (COP) (with and without heat recovery), and the local utility rates are the minimum input requirements for a feasibility study. From the equations necessary to derive these parameters, we identified the raw data points necessary to do these calculations. The appropriate instruments were then selected from available manufacturers to obtain measurements within tolerances determined through a sensitivity analysis. Finally, the data collection equipment was selected and the collection procedures and schedules were developed. Analysis procedures were designed that consisted of performing error checking routines, calculating the required input parameters using the previously defined equations, and reporting and graphing the results of the calculations.

Background

The existing chiller plant at the Irwin Army Hospital at Fort Riley, Kansas consisted of three (3) 200-ton steam turbine driven centrifugal chillers and two (2) 475 ton electric centrifugal chillers providing a total cooling capacity of 1550 tons. In 1994, it was determined that replacement of the steam turbine driven chillers was required due to their advanced age and deteriorated condition. Preliminary feasibility studies completed by USACERL showed a favorable discounted payback of just under 9 years for gas engine-driven chillers at this installation. Two (2) 350-ton Tecochill units using R-22 refrigerant were selected for the replacement and installed during the summer of 1995. Each 350-ton Tecochill unit is composed of two (2) 454 cu in. automotive

engines modified for use with natural gas that directly drive twin screw compressors through a gearbox with a ratio of 1.91:1.* Modulation of load between 65 and 350 tons is accomplished by throttling the engines. A hot gas bypass is used to match loads below 65 tons. Turndown ratios of approximately 10:1 can be attained with an Integrated Part Load Value (IPLV) Rating per ARI560 of 1.7. This will allow for efficient cooling during low load periods encountered during the winter months. A full load Coefficient of Performance (COP) of 1.2 (1.7 with heat recovery) is estimated without the use of the heat recovery option. Heat recovery of the 1.7 MBTU/hr of waste heat per unit will be utilized to preheat makeup water for the boiler plant and to provide hot water to the hospital. Specification sheets for the chillers and their components are in Appendix A.

Raw Data

The raw data points can be divided into two categories; individual chiller data and system data. System data includes outdoor air temperature, outdoor relative humidity, cooling tower pump and fan electrical consumption, secondary chilled water supply pump electrical consumption, heat recovery pump electrical consumption, and the local utility rate structures. Individual chiller data consists of the chilled water supply (CWS) temperature, chilled water return (CWR) temperature, chilled water flow, condenser water supply temperature, natural gas flow, chiller electrical consumption, heat exchanger (HEX) supply temperature, HEX return temperature, and HEX water flow.

Instrumentation

All of the water temperature readings will be taken with 1000 ohm platinum RTDs obtained from Synergistics, Inc. (Table B1). On new construction, the RTDs will be mounted in stainless steel thermowells that extend at least 3 in. (or to the midpoint) into the pipe. A silver-based heat conducting paste to improve heat transfer to the RTDs will be used in all of the thermowells. On existing systems, surface mounted RTDs will be use in place of the thermowells. The RTDs will be mounted on a surface free of corrosion and paint. Heat conduction paste will be used between the pipe and the RTD and will be covered with insulation to ensure that the temperature measurements are accurate as possible. An accuracy of ±0.1 °F is expected with proper calibration for all of the 1000 ohm RTDs. The location of the temperature sensors and flow meters are shown in Figure 1. Appendix A contains a description of the sensors.

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* 1 cu in. = 16.387 cm^3.

Table B1. Data collector setup and sensor description.

Symbol	Parameter	Sensor	Range	Vendor
	Synergistics #1			
T1	CWS #1 Temperature	RTD	Auto	Synergistics
T2	CWR #1 Temperature	RTD	Auto	Synergistics
F1	Chilled #1 Water Flow	Insertion	0-1000 GPM	Data Industrial
G1	Natural Gas Flow #1	Vortex Meter	4-20 ma	Yokogawa
KW1	Engine KW #1	CT	0-25 Amp	Synergistics
T3	HEX Water Supply Temperature #1	RTD	Auto	Synergistics
T4	HEX Water Return Temperature #1	RTD	Auto	Synergistics
F2	Heat Exchanger Flow	Insertion	0-450 GPM	Data Industrial
T5	Outdoor Air Temperature	RTD	Auto	Synergistics
RH	Relative Humidity	RHA-OUT	0-100%	Synergistics
T6	CWS #2 Temperature	RTD	Auto	Synergistics
T7	CWR #2 Temperature	RTD	Auto	Synergistics
F3	Chiller #2 Water Flow	Insertion	0-1000 GPM	Data Industrial
G2	Natural Gas Flow #2	Vortex Meter	4-20 ma	Yokogawa
KW2	Engine KW #2	CT	0-25 Amp	Synergistics
T8	HEX Water Supply Temperature #2	RTD	Auto	Synergistics
T9	HEX Water Return Temperature #2	RTD	Auto	Synergistics
KW3	Chilled Water Pumps KW	CT	0-100 Amp	Synergistics
KW4	Condenser Pumps KW	CT	0-200 Amp	Synergistics
KW5	Cooling Tower Fans KW	CT	0-100 Amp	Synergistics
T10	Condenser Water Temperature	RTD	Auto	Synergistics
	Synergistics #2			
T11	CWS #3 Temperature	Surf. RTD	Auto	Synergistics
T12	CWR #3 Temperature	Surf. RTD	Auto	Synergistics
KW6	Chiller KW #3	CT	0-2000 Amp	Synergistics
T13	CWS #4 Temperature	Surf. RTD	Auto	Synergistics
T14	CWR #4 Temperature	Surf. RTD	Auto	Synergistics
KW7	Chiller KW #4	CT	0-2000 Amp	Synergistics
T15	Engine Water In Temperature #1	RTD	Auto	Synergistics
T16	Engine Water Out Temperature #1	RTD	Auto	Synergistics
F5	Engine Water Flow #1	Insertion	0-150 GPM	Data Industrial
T17	Engine Water In Temperature #2	RTD	Auto	Synergistics
T18	Engine Water Out Temperature #2	RTD	Auto	Synergistics
F6	Engine Water Flow #2	Insertion	0-150 GPM	Data Industrial

The outdoor air temperature and relative humidity are measured using Synergistics, Inc. models TSA-OUT and TSA-RH. The TSA-OUT is a 1000 ohm RTD package designed to withstand severe environments and the TSA-RH provides a 4-20 ma signal proportional to the relative humidity. Both are shielded from the elements with a vented white plastic cover. The relative humidity sensor is accurate to within ± 3 percent over the entire range of the instrument.

Chilled water flow readings will be measured using a Data Industrial Corp. model 225B paddle wheel flow meter with a model 500 flow transmitter used to convert the

flow meter signal to a 4-20 ma signal. The model 225B consists of a paddle wheel flow meter and a brass gate valve that allows the flow meter to be removed from the system for maintenance or replacement without shutting down or draining the system. The flowmeters will be calibrated at the factory and verified on-site using measurements taken with a portable ultrasonic flowmeter. The flowmeters are accurate to within ±1 percent of the actual flow for flow rates between 1 and 30 ft/s (0.305 m/s).

The natural gas consumption will be obtained with a Yokogawa model YF102 vortex flowmeter for each chiller. Temperature and pressure compensating meters with a 4-20 ma or dry contact pulse output will be used where possible. If these compensating factors are not available, corrections for the mass flow will be based on the average pressure and temperature of the natural gas. The gas pressure will be obtained downstream of the building pressure regulator with a calibrated gauge. The average monthly gas temperature will be used to calculate the temperature correction factor, and will be verified by spot pipe measurements. The average Btu content of the fuel will be collected monthly from the natural gas supplier. Corrected gas flow measurements will be accurate to within ±1 percent of the actual flow.

Calibration of all of the temperature sensors will be referenced to a mercury thermometer. Lead wire resistance calculation will be measured by disconnecting the RTD and connecting a decade box set at 1100 ohms, a resistance corresponding to the resistance of a 1000 ohm platinum RTD at a temperature of 45 °F. The temperature difference measured at the data collector will be noted and a correction factor will be calculated and programmed into the data collector to compensate for the lead wire resistance. Chilled water supply and return temperatures require the greatest accuracy. These measurements will be verified by immersing the RTDs in an ice bath. Relative Humidity calibration will be done utilizing calibrated portable relative humidity monitors. This measurement will be spot checked monthly.

Electrical consumption readings will be measured utilizing potential transducers, current transformers, and current summing modules from Synergistics, Inc. The accuracy of the potential transducers and the current transformers are ±0.5 percent of the full scale reading. KW accuracy is ±0.5 percent of reading. The potential transducer provides a low voltage signal for polyphase service up to 480 Vrms. Current transformers are internally shunted to provide 0.333 Vrms signal at rated output. Current summers were utilized, where practical, to combine current measurements from similar equipment. Current measurements from groups of pumps and fans were summed into one measurement (i.e., each phase of the current measurements for the three primary chilled water loop pumps were combined into one current measurement, thus reducing the total number of channels required).

Data Collection Equipment

Model C180E data collectors from Synergistic Control Systems will be purchased to collect the chiller data. Each data collector has 15 analog input channels, 16 current transducer channels, 2 potential transducer channels, 16 digital input channels, 8 digital output channels, and 512 KB of memory. The analog channels accept 4-20 ma, 0-5 V, and 1000 ohm platinum RTDs. The optional modem and SYNET package will be used to program the data collectors and to download the data to USACERL.

The 40 VAC transformers will mounted in a separate metal box adjacent to the data collectors. The data collectors will be marked as #1, #2, etc., as necessary. Each data collector is capable of collecting operating data from 2 chillers, the outdoor air temperature, and the relative humidity. Table B1 shows all of the instruments, their functions, and the channels to which they will be connected for monitoring one and two chillers, respectively. Systems with more than two chillers will use combinations of the previously described design, omitting redundant outdoor air temperature and relative humidity measurements. Chiller and data collector numbering designations will be completed in a consistent manner at all installations to simplify the data analysis procedures.

Data Collection

Data will be collected with two Synergistic Model C180 data collectors. The data will be stored every 15 minutes and it will consist of the average of the data point over the 15 minute period. Data will be downloaded from the C180 every Monday morning (or the earliest possible time available). The data consists of all information collected from the previous Sunday night at midnight until the time of the data dump. The filenames consist of the first three letters of the month, the day of the month, the year, and the data collector ID (1, 2, etc). For example data downloaded from data collector #1 on June 26, 1993 would be stored in the file JUN26931.DAT. These files are in an ASCII format using real numbers with no column headers. The files will be converted into a FoxPro database file and checked for errors. The data is then merged into another database that contains all of the calculated values derived from the raw data. The necessary data and graphs can then be printed out for the weekly report. All of the raw data will be compressed and stored to the network, a hard drive, and a floppy disk or backup tape.

The raw data file will be stored in the following format with each 15 minute record consisting of:

Date, Time, Status, Counter, T1, T2, F1, T3, T4, F2, G1, KW1, T5, RH, T6, T7, F3, T8, T9, F4, G2, KW2, KW3, KW4, KW5,KW6

Each data point in the record will be examined to ensure that it falls within acceptable limits before it is saved. Unacceptable data will be written to a temporary error files sorted by the nature of the error. Separate files for general, temperature, and water and gas flow errors will be created. These error files should be analyzed every dump to determine the cause or causes of the error(s) and corrective action should begin immediately. Calculations will be made using the acceptable data and the results will be written to the FoxPro database for use in the analysis. The FoxPro database will be made up of 15 minute records with each record containing:

Date, Time, Chiller 1 Load, Heat Exchanger 1 Load, Chiller 1 Gas Consumption, Chiller 1 KW Consumption, Outdoor Air Temperature, Relative Humidity, Chiller 2 Load, Heat Exchanger 2 Load, Chiller 2 Gas Consumption, Chiller 2 KW Consumption, Parasitic KW Consumption, Total Load, Chiller 1 COP, Chiller 2 COP, Chiller1+HEX COP, Chiller2+HEX COP, System COP, System COP + HEX, System COP+ HEX + Parasitic KW

The hourly data record will consist of the above information plus additional fields for peak KW and for electricity and gas costs.

Equations

All of the loads are in Btu/hr.
All of the flows are in gpm
Specific heat of ethylene glycol solution at 25% is 0.91 Btu/lb-F
Specific Gravity of ethylene glycol solution at 25% is 1.039 at 50 °F
Assume: Chiller Output water temperature is 45 °F

Cv = 1 Btu/lb Density = 8.345 lbs/gallon

Heat Exchanger water temperatures is 200 °F

Cv = 1 Btu/lb Density = 8.035 lbs/gallon

If no glycol is in the system specific heat and specific gravity are 1.

BTU Equations

Chiller 1 Load = (T2 - T1) * F1 * 500.676

Chiller 2 Load = (T7 - T6) * F3 * 500.676

HEX 1 Load = (T4 - T3) * F2 * 482.1

HEX 2 Load = (T9 - T8) * F4 * 482.1

Total Cooling Load = Chiller 1 Load + Chiller 2 Load

(Temperature Correction Factor) TCF = 520 / [460 + Gas Temperature]

(Pressure Correction Factor) PCF = [14.73 + Gas Pressure] / 14.73

Gas Consumption = GF1(in ACF) * TCF * PCF * Btu/SCF

Btu/SCF can be obtained from gas utility (usually around 1000 Btu/SCF)

Load in tons can be obtained by dividing the above equations by 12,000.

All KW readings will be stored without conversion.

Coefficient of Performance Calculations

15 minute value:

Chiller COP = [Chiller Load] / [Gas Consumption + (Chiller KW) * 3412 / 4]
Chiller COP+HEX = [Chiller Load + HEX Load] / [Gas Consumption + (Chiller KW + HEX Pump KW) * 3412 / 4]

hourly value:

Chiller COP = [Chiller Load] / [Gas Consumption + (Chiller KW) * 3412]
Chiller COP+HEX = [Chiller Load + HEX Load] / [Gas Consumption + (Chiller KW + HEX Pump KW) * 3412]
System COP = [System Load] / [Gas Consumption + (Chiller KW) * 3412]
System COP+HEX = [System Load + HEX Load] / [Gas Consumption + (Chiller KW + HEX Pump KW) * 3412]
System COP+HEX+Parasitic KW =
[System Load + HEX Load] / [Gas Consumption + (Chiller KW +HEX Pump KW + Parasitic Power KW) * 3412]

Sensitivity Analysis

The sensitivity analysis will be performed based on the design data for a full load condition (350 tons) and a low load condition (65 tons). The design flow and temperature values will be assumed to be the actual values in this analysis. Table B2 shows

Table B2. Deviation due to instrument error.

Measurement	Full Load 350 tons	Actual Value	Part Load 65 tons	Actual Value
Chilled Water Flow (GPM)	840 ± 8.4		840 ± 8.4	
Chiller ΔT (°F)	10 ± 0.2		1.86 ± 0.2	
Gas Flow (SCFH)	3326 ± 33.26		450 ± 4.5	
HEX Flow	120 ± 1.2		120 ± 1.2	
HEX ΔT (°F)	28.3 ± 0.2		0 ± 0.2	
Chiller KW	5 ± 0.025		5 ± 0.025	
Parasitic KW	80 ± 0.4		80 ± 0.4	
Chiller Load (tons)	339.6 - 360.6	350	57.5 - 72.8	65
Hex Load (tons)	139.1 - 143.9	141.5	(-1) - 1	0
Chiller COP	1.18 - 1.28	1.23	1.44 - 1.85	1.64
Chiller COP + HEX	1.67 - 1.79	1.73	1.41 - 1.88	1.64
Chiller COP + HEX + PAR	1.55 - 1.66	1.60	0.90 - 1.19	1.04

the design (actual) values and the deviation of the measured values from the actual flows and temperatures and the calculated range of deviation for the chiller load, HEX load, and the COPs for the chiller with and without HEX and Parasitic Power. Equations used to calculate these values are from the previous section.

The calculated COPs at full load vary from the actual value by about ±4 percent while the COPs at the lower loads vary by nearly ±15 percent of the actual COP. This variance in the COP follows the variance in the ΔTs for the chiller. This analysis shows the importance of the accuracy required for the ΔT measurements across the chiller and the heat exchanger.

Weekly Report Format

The weekly report will consist of a summary of the operational data and the error logs. Graphs showing the chiller and system loads versus outdoor temperature (or heat index) and chiller and system COPs versus chiller load will be included. Any gross deviation from the previous data will be noted and investigated. Errors in the data will be identified and the procedures to correct the errors will be initiated and noted. Data will be converted to the hourly format on a weekly basis. The weekly reports will be used to make sure that both the chiller and data collection system are in proper working order and to incrementally process the data into its final form.

Monthly Report Format

The monthly report will include the same graph formats as the weekly reports, however the data will encompass the entire month and consist of hourly averages. Costs for electrical use and gas use will be calculated on a per-hour basis and summed for the entire month. The demand charge will be calculated from the peak KW value measured during on-peak hours of the month. A monthly maintenance cost will also be calculated from information obtained from the base personnel and included in the report. A regression model relating the cooling load to outdoor temperature and humidity will be developed for each month. Regressions relating chiller COP (or KW/ton) with the cooling load will also be developed. From these models, the monthly cost for electricity and gas will be calculated and compared to the actual values to validate the models. The models will be compared to previous months models to check for consistency. The report will be completed to use in the final report as a section.

Final Report Format

The final report will consist of four sections. The first section will discuss the background and objective of the project, including the sections of this report concerning data collection system design and analysis. The second section will consist of the monthly reports, which summarize the operation and maintenance costs of the systems and provide information on the reliability of the technologies. The third section will contain a summary of the annual costs and is where the LCC models will be performed. The fourth section will provide recommendations based on the study's findings.

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